BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Appraisal of Unmanned Planetary Program Alternatives to Voyager in the Period 1968-1975
Case 710

DATE: January 16, 1968

FROM: P. L. Chandeysson
M. Cutler

ABSTRACT

Several companies and NASA organizations have discussed possible interim unmanned planetary orbital missions and associated configurations with OSSA. The material presented by these organizations was briefly reviewed and compared in order to become familiar with the suggested alternatives and understand the similarity and differences between suggested approaches.

Generally, the suggested alternatives fall into two categories:

1. basing the design of the interim spacecraft on extensions of existing spacecraft and postponing any commitment to a Voyager-type design until the mid-70's;

2. early commitment to a Voyager-type design supported by a program of uprating the spacecraft at each opportunity to grow to full Voyager capability.

The studies in the first category are more tangible. The configurations used in these studies are fairly well defined and the associated schedules and costs are somewhat better understood. The definition is at a level that phase D of a procurement cycle perhaps could be considered.

The first approach appears well suited to

- obtaining useful planetary data
- keeping open the options as to which way to go in the mid and late 70's.

The second approach has all the unknowns of new developments, perhaps complicated by the long time in achieving each evolutionary step. The promise that this avenue holds out is the possibility of taking significant steps in developing and qualifying the next generation of automated spacecraft while obtaining precursor data.

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Approach 2 requires a careful examination to assure that the concept of early commitment to the evolutionary growth to a "full Voyager-type" spacecraft, over a protracted time period, is sound. The question is whether it can be done within approximately the same early costs as Approach 1 while returning timely data and not resulting in a commitment to a Voyager of limited flexibility.

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MEMORANDUM FOR FILE

1.0 INTRODUCTION

The "Alternatives to Voyager" studies of several contractors spontaneously provided to NASA last fall were reviewed from the viewpoint of defining useful planetary missions that could be performed in the early 1970's using existing technology. It was assumed that no new starts would be authorized in FY 1968, but that new starts in FY 1969 might be available.

The documents examined were prepared by:

- Boeing
- General Electric
- Hughes
- MAD-OART (Ames)
  Mission Analysis Division of Office of Advanced Research and Technology
- Martin
- McDonnell-Douglas
- North American Rockwell

The Boeing, General Electric, Hughes and MAD studies were aimed toward providing a configuration for an interim planetary program. The North American study was more of a replacement for Voyager with several suggested approaches of using Apollo derivative hardware in an unmanned planetary program. The Martin and McDonnell-Douglas studies were aimed toward providing an understanding of what the available alternatives are and did not espouse any particular configuration. A brief summary of the salient features of these studies is given in Table 1.

2.0 GENERAL

The documents varied widely insofar as which aspects of the problem they considered and also with regard to the depth of detail. In general, the aspects considered were:

- Launch Vehicle Capability
- Mission (Trajectory) Analysis
- Spacecraft and Subsystems Definition, Technology, and Science Planning

Generally the "studies" fall into two categories:

a. Basing the design of the interim spacecraft on extensions of existing spacecraft and postponing any commitment to a Voyager-type design until the mid 1970's. (Examples of this approach were Boeing and Hughes.)

b. Early commitment to a Voyager-type design supported by a program of uprating the spacecraft at each opportunity to grow to full Voyager capability. (General Electric is an example of this.)

There was some variation in the assumption of launch vehicle capability. Most of the documents set forth capabilities compatible with standard references. A standard for comparison is NASA TMX 60153, "Launch Vehicle Estimating Factors for Generating OSSA Prospectus 1967," dated November, 1966. Atlas-Centaur, Titan III-C and Titan III-C derivative vehicles appear to be adequate for pre-Voyager unmanned exploration of the near planets.

While the quality of the supporting technical detail varied from document to document, the supporting Planning (Schedules and Costs) detail was uniformly absent from all studies.

3.0 SPECIFIC COMMENT

3.1 Boeing

This is a proposal to modify the Lunar Orbiter (L.O.) to a Planetary Orbiter-plus-probe configuration. It is heavily supported by a prior study, "Study of Applicability of Lunar Orbiter Subsystems to Planetary Orbiter" (document NASA CR-66302, prepared under NASA contract).

Most (but not all) L.O. subsystems are satisfactory "as is" and, except for communications, modifications appear to be evolutions of existing subsystems rather than developments of new subsystems. The possibilities of incorporating expandable antennas to get larger diameters, increasing radiated power (using tubes currently in development), as well as digitizing video and using block coding techniques, are under study by Boeing. There is a question about the weight and sizes of the required power system for these missions. The suggestion is that Boeing may not have allocated enough weight to the power system.

Boeing recommends modification of the Marquardt engine O/F ratio (1.6 instead of 2.0) and nozzle expansion ratio (60:1 instead of 40:1). The 1.6 O/F ratio engine is an Apollo application of this hardware.

A study of the relative merits of injecting probes prior to or after the deboost of the spacecraft into planetary orbit is desirable before the final spacecraft and probe configurations are selected.

The nature of the modifications will require partial requalification of subsystems, and may require full spacecraft requalification.

Boeing suggests three alternative options, all of which maintain the 1969 Mariner flyby but postpone in time, to varying degrees, the '73 and '75 Voyagers and add the modified Lunar Orbiter-plus-probe as an interim measure to provide useful information in support of the Planetary Program and particularly in support of a Voyager-type mission in the late 1970's.

The Titan III class of launch vehicle was recommended. The lifting capability of the Titan III-C used in the Boeing study agreed with that of the NASA TMX 60153. The mission profiles used in the study for the years '71, '72, and '73 conformed to generally accepted Mars and Venus trajectories (C_3, time of flight, payload).

3.2 General Electric

This approach is described as a "stripped down" Voyager to perform a planetary orbiter mission. The lander is deferred and no interim probe alternative is proposed in the documentation. However, the concepts discussed are not incompatible with such probes.

G. E. proposes an evolutionary growth to "full Voyager technology," beginning with a mixture of Voyager and Mariner technology. Neither a growth plan nor the configuration was available at the time of these studies. The principal spacecraft subsystems (communication, data management, guidance, control) are thought as being "basically the same" as Voyager. The approach is one of striving for Voyager technology and using Mariner technology as an interim measure. As of early December, their concepts were still being analyzed.

The communication subsystem considered is the largest of the study configurations. A deployable 9.5-ft diameter antenna may require development. The radiated power and bit rate appear to be compatible with the design approach.

Development of a spacecraft propulsion module is required to achieve the relatively high weight proposed for the planetary orbit. This development is predicated on the existing Titan transtage engine (AJ 10-138, 8000 lbs vacuum thrust, I_{sp}302 sec). Space flight qualification for 200 days may be a development problem. In addition, operation at a new O/F ratio of 1.6 is proposed to improve I_{sp}. If this engine is to be used at 8000 lbs thrust, the proposal is not clear as to whether the structural weight of the deployed spacecraft is compatible with the g-loading. Possible alternatives to, and questions about, the propulsion system need clarification. The performance numbers used in the G. E. study for spacecraft engines were idealized calculations based on abstract engines.

The G. E. study puts the spacecraft into an elliptical parking orbit around the earth with the booster and then uses a spacecraft propulsion system for planetary injection. This results in a large payload in orbit about the planet by introducing the equivalent of a kick stage. The worth and cost of this large capability, relative to a system not required for the planetary injection, should be carefully examined since it requires development of a spacecraft propulsion module of fairly large size with two large burns separated by over 100 days.

3.3 North American Rockwell

This proposal explores the possibility of utilizing the Apollo SM and, in one case, the CSM as a transplanetary injection stage from a 100 n.m. earth parking orbit. The launch vehicle is a Titan III-C. The baseline SM serves as a spacecraft propulsion module to insert a payload (such as a planetary orbiter/lander) into a 100 n.m. earth parking orbit and subsequently provides the propulsion for the transplanetary trajectory. The SM supports the payload, provides the RCS for attitude control, and provides the midcourse corrections on the transplanetary flight path. Velocity increments in the vicinity of the planet must be provided by the spacecraft propulsion subsystems. Another option, using the

SM as a terminal booster stage instead of as a planetary bus, was also proposed. The spacecraft configuration was not defined.

There appears to be a sufficient number of changes to the SM to make its value as existing hardware of questionable worth in an unmanned planetary application. There may be as many problems due to SM constraints as there would be with a new spacecraft design. A full flight qualification of the SM as as a planetary spacecraft probably would be necessary.

Integration of the SM with any other vehicle, other than the Saturn class, may present sizable hidden development costs. The North American study suggests so many alternatives using Apollo derivatives that substantial study would be required to fully evaluate their potential.

3.4 Martin-Marietta

A number of mission alternatives to Mars and Venus were examined. Primary emphasis is on the capability of Titan III class launch vehicles for planetary missions. Some consideration is given to Atlas-Centaur and Saturn V. Trajectory considerations are detailed in arriving at permissible spacecraft weights.

Spacecraft weight is broken down by subsystems and scientific equipment. A possible experiment complement is defined. Several spacecraft-probe configurations are conceptually examined. No design was recommended.

The document discusses the escalation of the technology level from Mariner to Voyager with each mission step. There is insufficient detail to ascertain how this concept might be implemented. The only existing hardware discussed is the booster.

3.5 McDonnell-Douglas

This study is a survey of several Planetary Program alternatives including:

a. Planetary orbiter/probes (based on Lunar Orbiter or Mariner) in the 1971-73 time period culminating in a full Voyager in 1975.

b. A "stripped" Voyager (impact probe instead of soft lander) to fly in 1973.

c. A planetary spacecraft to Mars in 1973 as part of a "shared" Saturn V launch (earth orbital laboratory).

The detail on the spacecraft is limited to conceptual sketches and gross weight estimates for each spacecraft or probe and for the experiments.

For the period 1971-73, the Atlas-Centaur or Titan III is apparently compatible with the missions studied. The mission (trajectory) analysis was not detailed. The stated C_3 is in the correct range for the planetary missions suggested.

3.6 Hughes

This is a specific study to use a modified ATS-1 (Applications Technology Satellite) as an ATS-Mars to be launched from an Atlas-Centaur for the 1971 Mars opportunity. The principal experiments are the ATS camera and RF occultation. There is a large margin between the spacecraft weight and the launch vehicle capacity. It is not clear whether this margin can be used efficiently to increase the experimental payload. Changes to the ATS are required in four areas:

a. Telemetry and command system must be changed to DSIF S-band and would be partly based on Surveyor technology. An electronically despun S-band antenna would be a new development.

b. Thermal control system would be active instead of passive using insulation and heating blankets on the solid rocket motor (200 days in space before deboost.

c. Cylindrical solar array must be extended to maintain power at 1.5 AU.

d. A tape recorder and buffer storage must be added to balance transmission rate.

The suggested communication link changes to DSIF S-band are largely based on Surveyor technology. Bit rate is low resulting in long transmission times. The approach is open to question due to the long transmission times. A larger bit rate may be a possibility with modifications to the proposed communication system.

The active thermal control system, as presented may be over-simplified and may require some development and spacecraft modification. The number of system changes are such that the spacecraft may have to be requalified.

Flexibility and growth are minimal, particularly considering the spin stabilization mode which may limit the integration of other experiments, even though additional weight capacity is available. There is a question of the compatability of IR and optical experiments on the ATS in Mars orbit.

Stated launch vehicle capability (Atlas-Centaur) is conservative and mission (trajectory) analysis is adequate.

3.7 Mission Analysis Division of OART at Ames

An Agena spacecraft, using Mariner '69 technology, is proposed for the 1971-73 Mars/Venus opportunities. The concept requires uprating the Agena from a terminal stage to a spacecraft propulsion module by providing an increased capacity RCS system for attitude control and an uprated main propulsion system for trajectory control. This latter application requires uprating the Agena to a 200-day restart capability in space as well as a possible propellant change to N_2O_4/Aerozene 50 from IRFNA/UDMH. Another new requirement is the incorporation of a secondary propulsion system on the Agena for midcourse corrections. Subsequent detailed study would have to be performed before the feasibility of this could be considered demonstrated.

This combination orbits 557 lbs of communication, electronics and instrumentation (cameras, spectrometers, radiometers, etc.) and a 200-lb probe with accelerometers, pressure and temperature sensors, radiometer, spectrometer, and Langmuir probe. The probe would be released from orbit.

Technology is based on Mariner '69. A ten-foot diameter steerable DSIF S-band antenna is required; this would require development.

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Attachment
Table 1

TABLE I COMPARISON OF SALIENT FEATURES OF ALTERNATIVE APPROACHES

	BOEING	GENERAL ELECTRIC	NORTH AMERICAN	MARTIN	McDONNELL-DOUGLAS	HUGHES	MAD-AMES
GENERAL	Specific study to Modify the Lunar Orbiter Spacecraft as a Planetary Orbiter. Development work needed in scient'fic instruments, and on certain subsystems	Concept of developing a new Planetary Spacecraft which would evolve into a Voyager Spacecraft.	Concepts of how Apollo derivative hardware might be used in unmanned planetary exploration. One concept is summarized below.	Study of alternatives that are available. This summarizes one of 15 Planetary Orbiters Described by Martin. Launch Vehicles ranged from Atlas/Centaur to Saturn V	Survey of Several possible alternatives. This summarizes one of 8 Evolutionary Planetary Program Candidates leading to a Voyager Mission in 1975	Specific study to Modify the Applications Technology Satellite as a Mars Orbiter.	Specific study to Modify the Agena as a Planetary Orbiter. Modifications are extensive; S/C subsystems are new.
MISSION							
Trajectory	Mars Type I, Venus	Mars Type II, Venus Type I	Mars Type I, Venus Type I & II	Mars Type I, Venus Type I & II	Mars, Details not defined	Mars Type I	Mars Type I & II, Venus Type I & II
Launch Window	30 days	20 Days	15 & 30 Day Windows considered	30 Days		34 Days	not defined
C_3 (km^2/sec^2)	8.8 to 16.6 for Mars, 7.4 to 20 for Venus	15.4 to 18.6 for Mars, 15 to 19.1 for Venus	8.15 to 27.8 for Mars, 6.1 to	15.0 to 29.0 for Mars, 6.8 to 21.6 for Venus		78.9 to 10.0 for Mars	not defined
Orbit (km/sec)	1.2 to 1.67 for Mars, 1.55 to 2.15 for Venus	1.03 to 1.20 for Mars, 1.25 to 1 1.44 for Venus	1.4 to 4.6 for Mars, 1.9 to 2.9 for Venus	V and Payload ratios given		2.9 km/sec	1.05 to 4.07 for Mars, 1.7 to 3.94 for Venus
POWER SUPPLY	Solar panels and batteries, Modified Lunar orbiter subsystem	not defined	not defined	Six Solar panels and batteries Modified Lunar Orbiter subsystem	Not defined	Solar Panels and Batteries, Modified ATS	Solar Panels and Batteries, New subsystems
COMMUNICATIONS	6-Foot diameter antenna 30 db, Two -watt TWT's, S-band, Highly Modified Lunar orbiter subsystem with Saturn V TWT's	9 1/2-Foot Diameter Antenna, 50 Watts radiated power, S-band	not defined	3 Foot diameter antenna, Two-35 Watt TWT's, S-band, Modified lunar orbiter subsystem	Not defined	Electronically Despun 16 Element S-band array, 20.5 DB Gain, 20 watts Radiated. Transmitter based on ATS VHF array	10 Foot Diameter Antenna 20 Watts Radiated, S-band, New subsystem
ORBIT PROPULSION	Modified Lunar orbiter subsystem with enlarged Tanks, R-4D-3 Engine, 50/50-N_2O_4 gives 290 Sec. Isp Minimum	New "Dual Purpose" Module using Titan Transtage Engine (8000# Thrust), same stage used for Injection Propulsion out of Earth orbit.	New Liquid Propulsion subsystem, I_{sp} = 300 Sec Mass Fraction = 0.85	New storable stage with 6-1400# Thrust Monopropellant Engines	New Storable Stage, Type not defined	Fixed Impulse solid rocket. JPL Starfinder used on ATS Satellite I_{sp} = 281 sec.	Agena D main engine
TECHNOLOGY REQUIRED	The Payload subsystems of Planetary orbiters represent a major area of required Technology Development. The Long term operation of Photographic exper'ments use of high resolution Image Notion compensated television cameras and Imaging Radars should be investigated. Sterilizable entry probes, possibly including simple Landers should also be Investigated. Engines other than derivatives of the Apollo RCS have yet to be qualified for long duration Application.						
		Communications Subsystem has desired Data Capacity but would require Development. Growth to Voyager is not Obvious.	Spacecraft Concept not discussed			Development of S-band array from VHF may involve new technology. The use of a Hi-Gain (31 DB) antenna is necessary, and would be a new development.	Agena Restart after 200 days in Space most Spacecraft subsystems would be new developments.
SCHEDULE & FUNDING	Supporting Detail was insufficient to make a comparison of the Program Schedules and Costs.					Deployment of a Probe from this Spin stabilized spacecraft is not discussed and may be difficult.	
WEIGHT IN ORBIT	1415# for Mars, 1410# for Venus (maximum) based on Titan III C Launch Vehicle	2500# for Mars in '73, 2700# for Venus in '73 (plus spent stage). Based on Titan III C launch into Elliptical earth orbit	1650# for Mars in '73, 110# for Mars in '75, 1800# for Venus in '73, 2200 for Venus in '75. Based on SIB launch vehicle	700# based on Atlas/Centaur Launch Vehicle	820# Based on Atlas/Centaur Launch Vehicle	800# Based on Atlas/Centaur Launch Vehicle in 1971	4300# in '71, 3500# in '73, 3900# in '75 for Mars, 2800# in '72, 3500 in '74 for Venus based on Titan III D Launch Vehicle
EXPERIMENT WEIGHT	585# for Mars in '71 & '73, 290# for Venus in '72 540# for Venus in '73	233# Orbital Science instruments	not specified	140# Orbital Science instruments	200# Orbital Science Instruments	17.0# Orbital Science Instruments IR and Optical experiment compatibility is a question.	267# Orbital Science plus Two or more 200# Entry Probes except Venus '72.

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